THE ARABIAN SEA: A NATURAL EXPERIMENT IN PHYTOPLANKTON BIOGEOGRAPHY

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LONG TERM GOALS

The structure of the phytoplankton community influences the optical properties of the water column, the size distribution and growth rate of higher levels of the food web, and may also control resiliency and stability in marine ecosystems. These small organisms represent a wealth of biodiversity and, because of their small size and rapid growth rates, they have the potential for a rapid evolutionary response to environmental change. I seek to understand the dynamics of marine ecosystems through study of the ways that natural selection influences the distribution and evolutionary trajectory of marine phytoplankton in nature. An important component of this research is an evaluation of the conditions under which water mass history can be used to evaluate changes in the selection regime - i.e. in a fluid environment, is the water mass equivalent to the habitat of an planktonic organism? How much coherence is there between the distribution of a particular community type and water masses of particular character? If water masses define the habitat boundaries, then modern oceanographic techniques can be used to describe the time rate-of-change of conditions in the water mass, thus opening the door to measuring and modeling the selection regime and the response to selection by natural populations of phytoplankton and other microorganisms.

OBJECTIVES

Examination of CZCS imagery led to the hypothesis that the phytoplankton bloom associated with the Southwest Monsoon in the Arabian Sea is “seeded” by neritic taxa introduced into offshore waters by the general reorganization of currents which accompanies the Southwest Monsoon. Specific hypotheses to be tested were:

1) that major bloom-forming taxa are large diatom and dinoflagellate species typically described as “neritic” taxa adapted to coastal conditions of temperature, water column optics, and nutrient availability,
2) that these taxa go extinct in the offshore waters during the Northeast Monsoon, when natural selection favors species more adapted to oceanic conditions,
3) that bloom-forming taxa and coastal forms of marine *Synechococcus*, are reintroduced offshore at the beginning of each upwelling period by the

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general reorganization of currents that occurs during the spring intermonsoon period, and

4) that the dominant taxa are genetically diverse; natural selection will cause a general increase in the frequency of ecotypes adapted to the nutrient regime offshore relative to the frequency of ecotypes adapted to the neritic environment as the monsoon progresses.

APPROACH

This project has a laboratory and a field component. The field program was designed to identify the distribution of neritic and oceanic taxa of phytoplankton by traditional methods of microscopy and by spectrofluorometric methods. Chroococcoid marine cyanobacteria contain phycoerythrin (PE), which is a distinctive and highly fluorescent photosynthetic pigment. Different strains of PE-containing cyanobacteria have different fluorescence signatures based on the chromophore composition of the particular phycoerythrin they synthesize. Earlier work in the North Atlantic and Pacific showed that forms with high amounts of the chromophore phycourobilin (PUB) were the dominant forms in blue-water environments and that forms with low amounts of PUB chromophores were common in neritic waters; “high’ and “low” PUB PEs can be relatively easily distinguished from one another by their fluorescence signature and, in this work, we use the spectral signature of PE to follow the distribution of coastal forms of marine cyanobacteria, and more traditional morphology-based methods of identification to follow the distribution of neritic taxa of diatoms and dinoflagellates. Our cruises were organized around the goal of understanding upper ocean dynamics and included ten days of Seasoar operations to map upper ocean hydrographic properties, light fields, DOC distributions, and nutrient concentration. NRL investigators provided extensive remote sensing data, and have developed models of wind-driven circulation and upwelling strength that agree well with physical measurements and remote sensing. Thus, my data on the distribution of different taxa or pigment types can be interpreted in the context of larger-scale processes by reference to the data collected by other participants in the cruises.

The laboratory portion of the cruise involves analysis of the field samples and isolation of multiple strains of some of the phytoplankton taxa that dominated during the monsoon period. Characterization of the physiological properties and genetic diversity among the different strains of each taxa will provide evidence to support or reject the hypothesis that populations of the dominant taxa are genetically diverse (see hypothesis #4 above).

WORK COMPLETED

The field work for this project is completed, with more than 2000 phytoplankton samples collected and over 600 fluorescence spectra collected and analyzed. The dominant net phytoplankton have been identified in priority samples and essentially all data on the distribution of different spectral forms of phycoerythrin-containing cyanobacteria is complete for all cruises. Much progress has been made in analyzing the data in the context of what the ONR/NRL cruises and models reveal about general patterns of circulation during the monsoon (See below). Finally, physiological research and genetic analysis of several strains of chroococcoid cyanobacteria from the Arabian Sea has begun.

RESULTS

While diatoms form huge, nearly monospecific blooms in newly upwelled water along the coast, our data indicate that chroococcoid cyanobacteria can become extremely abundant in upwelled water after diatom growth has changed nutrient composition. We measured some of the highest concentrations of chroococcoid cyanobacteria observed in the world ocean during the Southwest Monsoon. The seasonal pattern of abundance showed that these organisms were common along the coast and in the Gulf of Oman throughout the year, but that they had a seasonal cycle of abundance in the south central Arabian Sea, with lowest numbers offshore (and highest numbers onshore) observed on our June/July cruise.

Three basic spectral forms of phycoerytrhin-containing cyanobacteria were identified based on the fluorescence signature. These were: 1) forms found in water of very high salinity and temperature and which have relatively low amounts of PUB, 2) forms with high amounts of PUB that are found in low nutrient water of intermediate temperature and salinity, and 3) forms with low amounts of PUB found in relatively cool, fresher water with higher nutrient availability. At present, these are identified as “Gulf of Oman” types, “Ambient Water” types, and “Upwelling-Associated” types, respectively. In June and early July, the “Upwelling Associated” forms were the dominant forms at all our stations along the coast, but they were absent offshore; by September, coastal forms were common both offshore and further offshore. The replacement of “Ambient Water” types by “Upwelling Associated” types appears to reflect offshore transport of neritic forms of PE-containing cyanobacteria by coastal filaments and jets. This interpretation is supported by physical data, modeling results, and remote sensing data.

IMPACT

The basic hypothesis underlying this work was that offshore transport associated with intense coastal upwelling during the SW Monsoon leads to what is essentially a coastal bloom on a sub-basin scale. Our hypothesis, that the dominant taxa in the bloom were neritic taxa transported offshore by features of the general circulation appears to be true for the chroococcoid cyanobacteria. Further, the concentration of these organisms is so high in the Arabian Sea that phycoerythrin and the photoprotective pigments of marine cyanobacteria should make a significant contribution to ocean color and irradiance attenuation.

Finally, as predicted, a seasonal pattern of abundance of neritic organisms offshore is associated with waxing and waning of SW monsoon effects, but it is a cycle that is offset by several months from the cycle of wind-forcing used to define the monsoon period. From our data, it would appear that community organization that might be described as “SW Monsoon community structure” did not develop throughout the basin until at least a month after monsoon winds had fully developed, and it also appeared that “SW Monsoon” community structure persisted at least a month after winds had relaxed. Thus, this is a system in which the timescales and intensity of perturbation required to dramatically reorganize ocean systems might be examined for application to other basins.

TRANSITIONS

NRL Investigators are using data from our net samples to assess the suitability of using bioluminescence kinetic data to discern differences in the bioluminescence community structure.   Our data may also help to “ground truth’ predictions of the NRL bioluminescence model.

RELATED PROJECTS

The net tows we collected are providing data for NRL investigators studying bioluminescence (see above) and have been used by Dr. Sharon Smith (University of Miami) in her NSF-funded study of copepod abundance and productivity during the Southwest Monsoon. My data are being used in descriptions of the impact of filaments and jets on the regional ecosystem by the WHOI Seasoar team (K. Brink and C. Lee, with B. Jones of Univ. Southern California), J. Kindle (ONR), and R. Arnone (ONR). I am working with Drs. Frank Hoge and Bob Swift (NASA) to provide ground-truth for their assessment of the distribution of high and low PUB-forms of phycoerythrin using aircraft-borne LIDAR, and I am working with the NRL remote sensing group to identify optical properties associated with water massess dominated by different types of phytoplankton. Genetic characterization of my cyanobacterial clones is being done in collaboration with Dr. Brian Palenik (Scripps Inst. Oceanography) who has an NSF-funded project to characterize the genetic diversity and phylogenetic relationships of marine cyanobacteria.